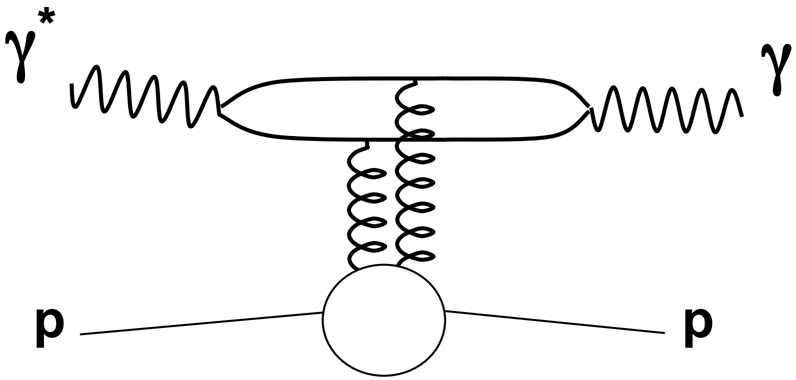
BROOKHAVEN NATIONAL LABORATORY

DVCS from HERA to EIC

Salvatore Fazio
BNL



EIC Collaboration Meeting

The Catholic University of America

July 28-31, 2010

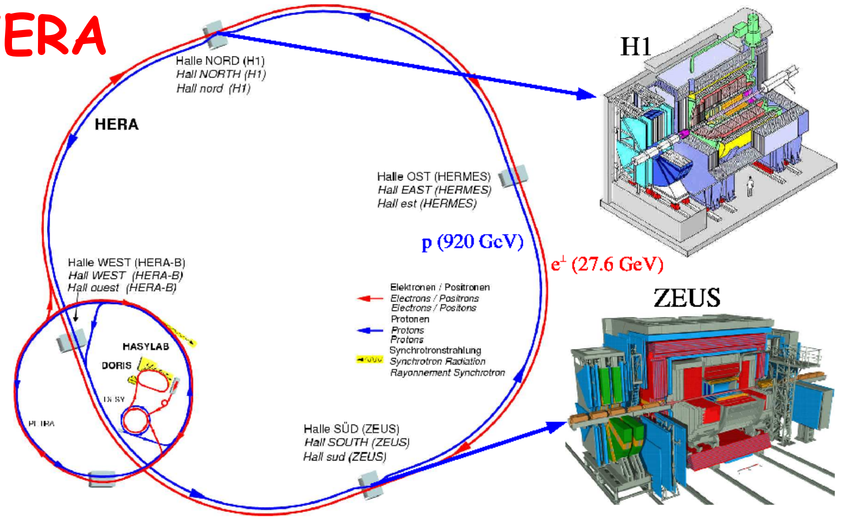
Planing of the talk

- From HERA to EIC
- Exclusive Diffraction in ep collisions
- Real photon production (DVCS)
  - Strategy
  - Hera results
  - Extension to EIC
- Summary

HERA and EIC colliders

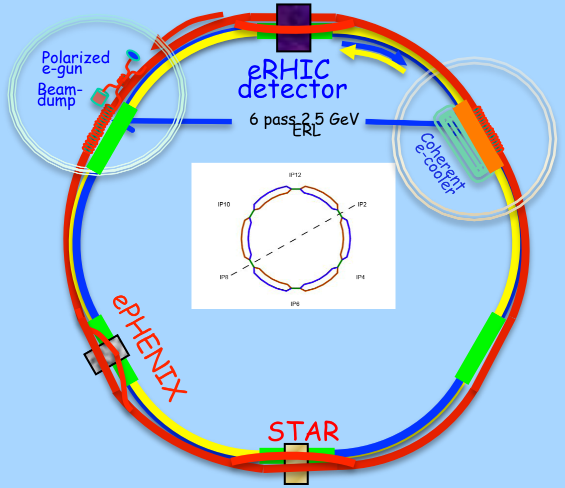
- 27.5 GeV electrons/positrons on 920 GeV protons →$\sqrt{s}$=318 GeV
- 2 colliding experiments: **H1 and ZEUS**
- Total lumi collected at HERA: **500 pb^{-1}**, polarization of electrons/positrons at HERA II

HERA



Detectors not originally designed for forward physics, Roman pots added later

EIC/eRHIC

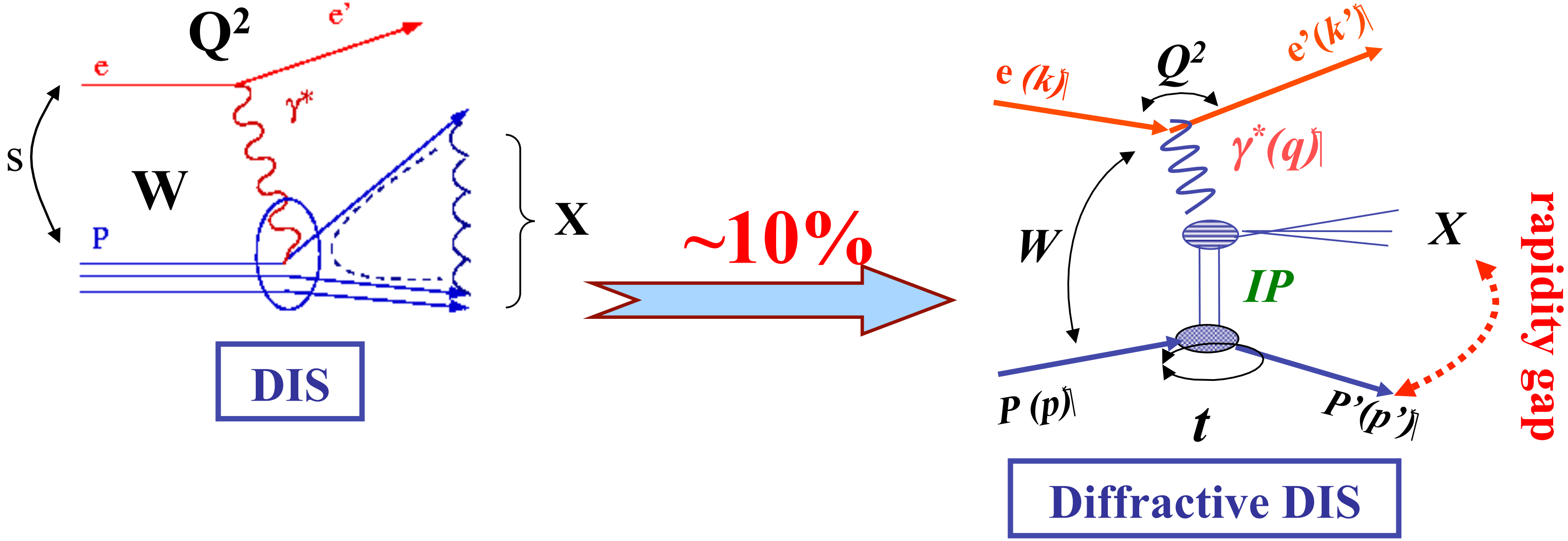


- **20 - 30 GeV electrons on 325 (125) GeV protons (nuclei). Polarization of electrons and protons (nuclei)**
- **Lumi: 1.4 x 10^{34} cm^{-2}s^{-1}**

For exclusive diffraction the concept is similar to HERA but:

- **Dedicated forward instrumentation**
- **Higher tracker coverage**
- **Very High lumi!**

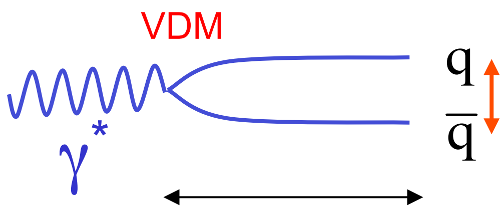
Diffraction in ep collisions



- ***p*** escapes in the beam pipe
- no quantum numbers exchanged btw ***γ**** and ***p*** **-> no colour flux → large rapidity gap**
- Providing a perturbative QCD motivated description of strong interactions

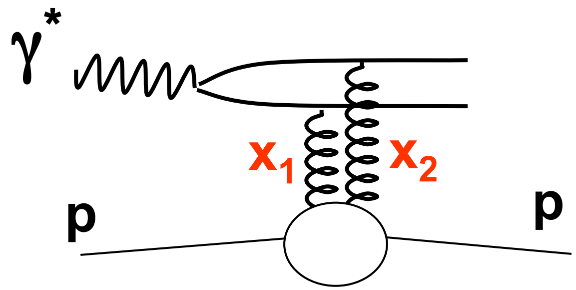
Diffraction in ep collisions

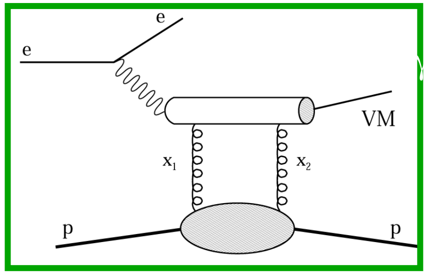
Before HERA diffraction was studied in hadron-hadron interactions



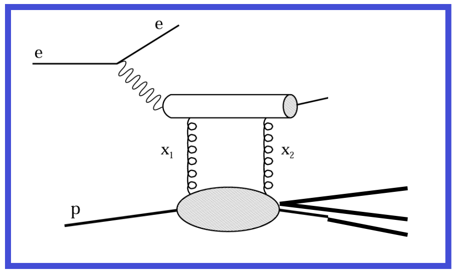
$$\propto \frac{1}{\sqrt{Q^2 + M_{q\bar{q}}^2}}$$

$$\propto E_\gamma \sim W^2 \sim 1/x$$

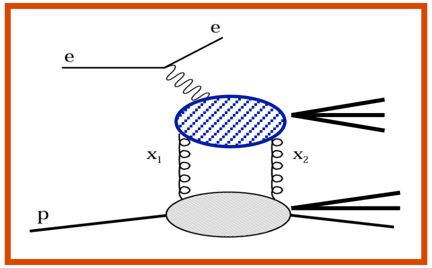




Elastic diffraction: *ep* → *e (VM,γ) p*

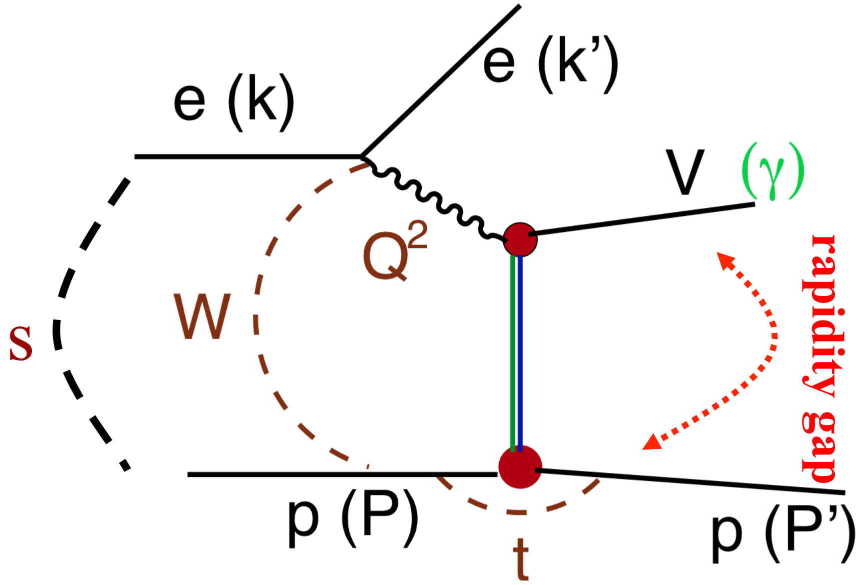


Single diffractive dissociation: *ep* → *e (VM,γ) Y*



Double diffractive dissociation: *ep* → *e X Y*

Exclusive diffraction



Main kinematic variables

electron-proton centre-of-mass energy:

$$s = (k+p)^2 \approx 4E_eE_p$$

photon virtuality:

$$Q^2 = -q^2 = -(k-k')^2 \approx 4E_eE'_e\sin^2\frac{\theta}{2}$$

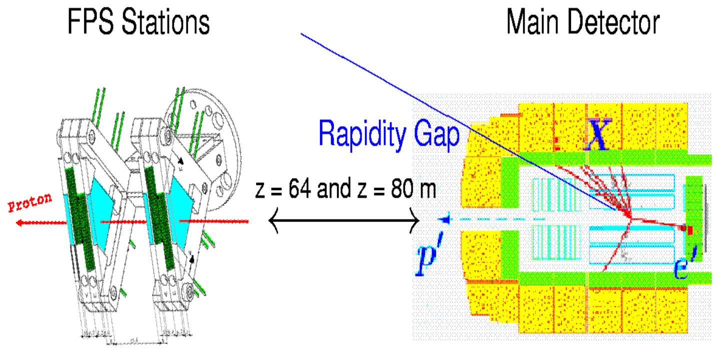
photon-proton centre-of-mass energy:

$$W^2 = (q+p)^2, \text{ where}: m_p < W < \sqrt{s}$$

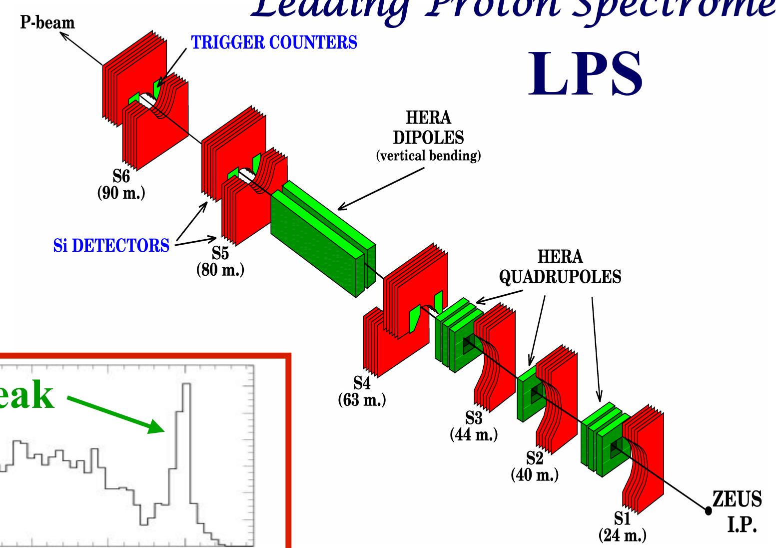
square 4-momentum at the *p* vertex:

$$t = (p'-p)^2$$

- **Vector Mesons production in diffraction**
- **Deeply Virtual Compton Scattering**

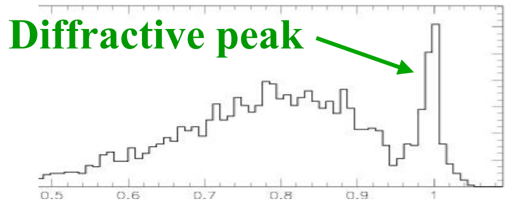


Leading Proton Spectrometer



<u>*p* tag method</u>

- o **Measurement of *t***
- o **Free of p-diss background**
- o **Higher M_X range**
- o **Lower acceptance**

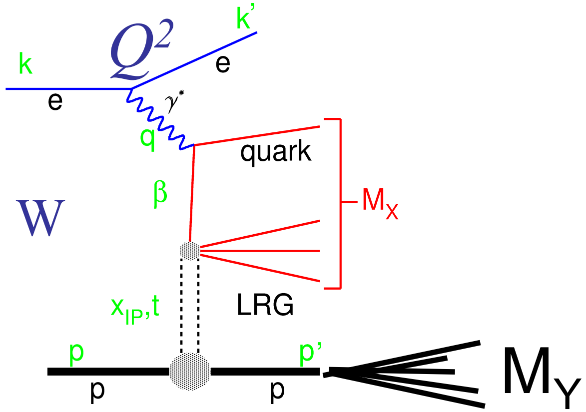


$$x_L = \frac{p'_z}{p_z} \approx 1 - x_{IP}$$

NB: if scattered proton not detected, background from proton dissociative events

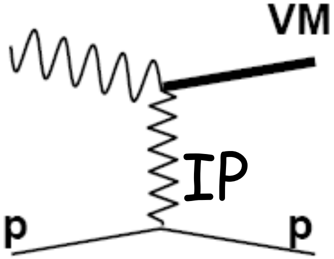
<u>Large Rapidiy Gap method</u>

- ❑*X* **system and e' measured**
- ❑**System *Y* not measured, some theoretical and experimental uncertanties**
- ❑**Integrate over $t<1GeV^2$ and $M_Y<1.6$ GeV**
- ❑**High acceptance**

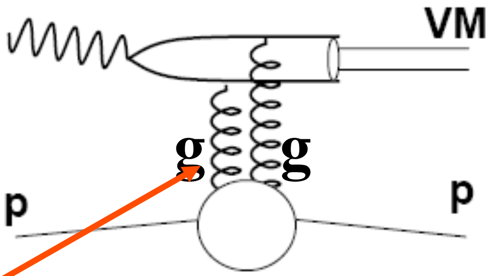


Soft and hard diffraction

Vector Meson production (ρ, φ, J/ψ, Y, γ))



'soft'



2-gluon exchange (pQCD)

'hard'

Cross section proportional to probability of finding 2 gluons in the proton

Gluon density in the proton

$$\begin{cases} \sigma \propto \left[xg\left(x, \mu^2\right) \right]^2 \\ \mu^2 \propto \left(Q^2 + M^2\right) \end{cases}$$

$$\sigma(W) \propto W^{\delta}$$

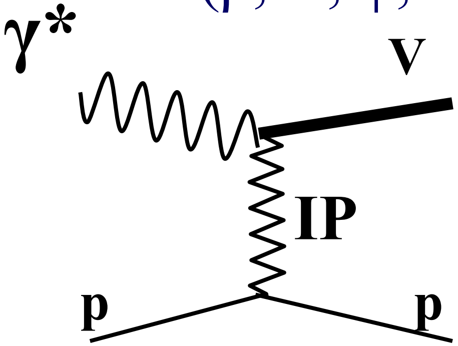
δ Expected to increase from soft (~0.2, "soft Pomeron") to hard (~0.8, "hard Pomeron")

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

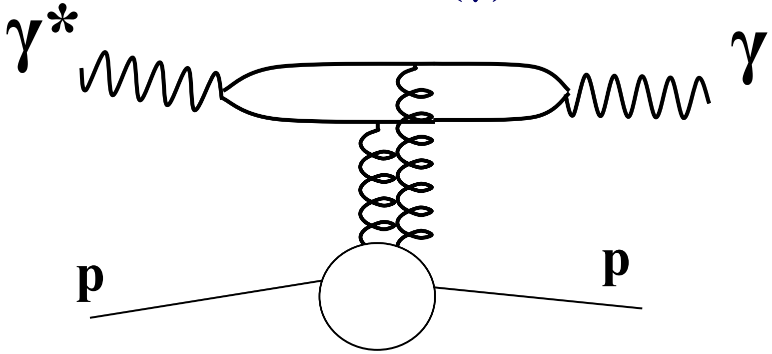
b expected to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

Deeply Virtual Compton Scattering

VM (ρ, ω, φ, J/ψ, Y)



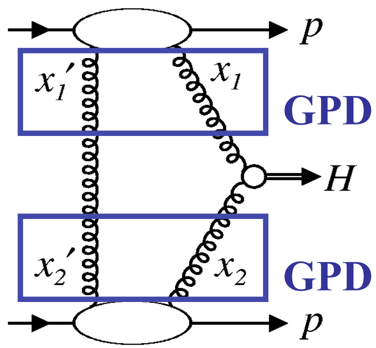
DVCS (γ)



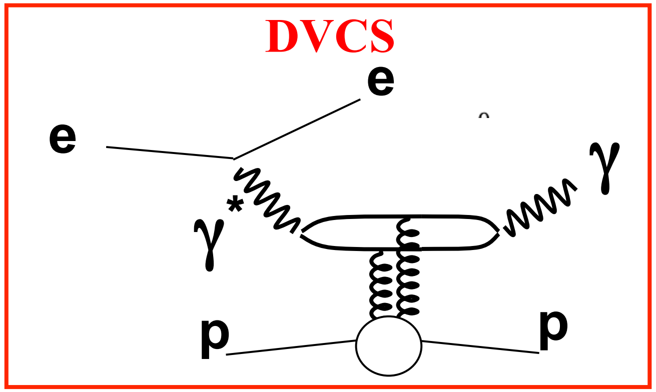
Scale: $Q^2 + M^2$ ⟷ Q^2

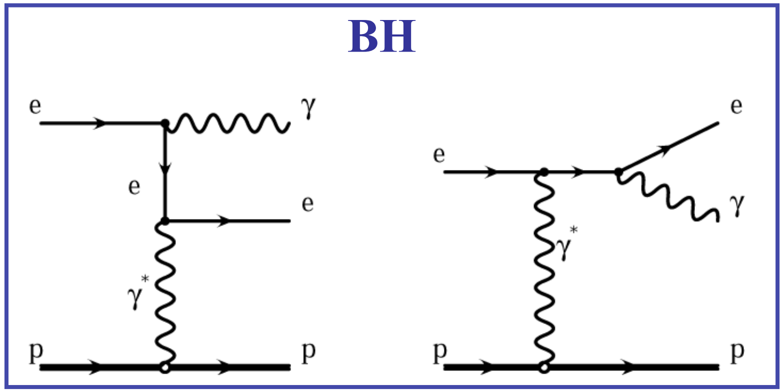
DVCS properties:

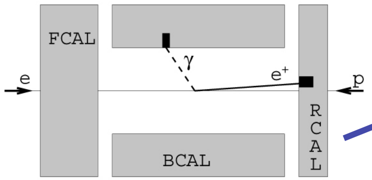
- **Similar to VM production, but γ instead of VM in the final state**
- **No VM wave-function involved**
- **Important to determine Generalized Parton Distributions sensible to the correlations in the proton**
- **GPD$_s$ are an ingredient for estimating diffractive cross sections at LHC**

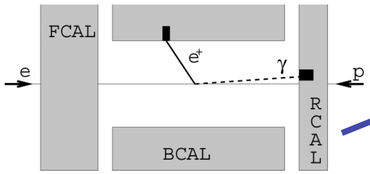


DVCS @ ZEUS - Strategy









γ sample: no tracks matching to the second candidate **(DVCS+BH)**

e sample: a track match to the second candidate **(BH+ dilepton + J/ψ)**

Wrong-sign sample: a negative track match to the second candidate **(dilepton + J/ψ)**

DVCS @ ZEUS – Selection criteria

$L = 61.14\ pb^{-1}$

- **$99e^{+}$-00 ZEUS data**
- **Two Sinistra candidates**
- **First candidate in RCAL**
- **Second candidate in RCAL or in BCAL**
- **1 or 0 tracks**
- **rear box cuts**
- **Elasticity cut**
- **Energy in FCAL < 1 GeV and in FPC < 1GeV**
- **-100 < Zvtx < 50 cm**

Monte Carlos:

GenDVCS	(400k DVCS events)
Grape-Compton	(400k el. BH events 400k inel. BH events)
Grape-dilepton	(150k dilepton events 150k inel. dilep. events)
DiffVM $J/\Psi \longrightarrow e^{+}e^{+}$	

JHEP05(2009)108

Kinematic region:

$1.5 < Q^2 < 100\ GeV^2$

$40 < W < 170\ GeV$

Energies & angle:

$E_1 > 10\ GeV$

$E_2 > 2\ GeV$

$\theta_2 < 2.85$

PLB 573 (2003) 46-62

Kinematic region:

$5 < Q^2 < 100\ GeV^2$

$40 < W < 140\ GeV$

Energies & angle:

$E_1 > 15\ GeV$

$E_2 > 2.5\ GeV$

$\theta_2 < 2.75$

MC simulation

GenDVCS

$$\frac{d^3\sigma^{DVCS}}{dx dQ^2 dt} = \frac{\pi^2\alpha^3 s\left(1+(1-y)^2\right)}{2xR^2Q^6} e^{-b|t|} F_2^2\left(x,Q^2\right)\left(1+\rho^2\right)$$

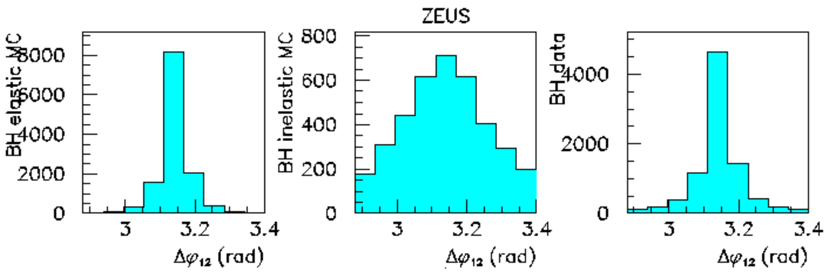
Written by P. Saull [1999]
Based on:
Frankfurt, Freund and Strikman (FFS)
[Phys. Rev. D 67, 036001 (1998).
Err. Ibid. D 59 119901 (1999)]

MILOU

Written by E. Perez, L Schoeffel, L. Favart
[arXiv:hep-ph/0411389v1]

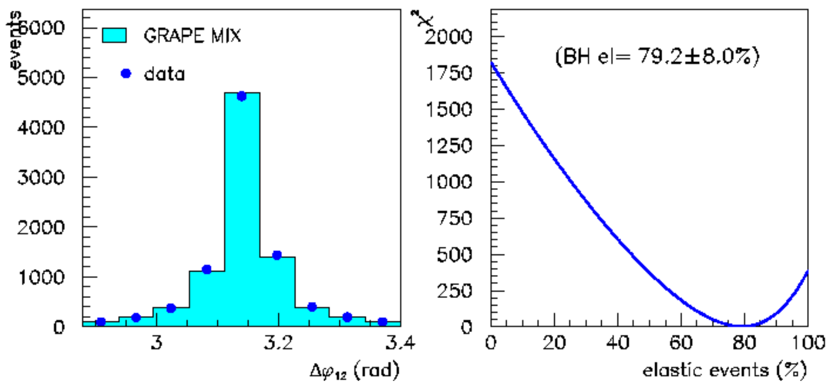
- GPDs, evolved to next-to-leading order
- provide the real and imaginary parts of Compton form factors (CFFs), used to calculate cross sections for DVCS and DVCS-BH interference.
- Proton dissociation ($ep \rightarrow e\gamma Y$) can be included.

BH contribution



MC BH elastic. MC BH inel. BH data

The fraction of el. and inel. BH can be estimated looking at the shape of the difference in the azimuthal angle between the electron and the photon



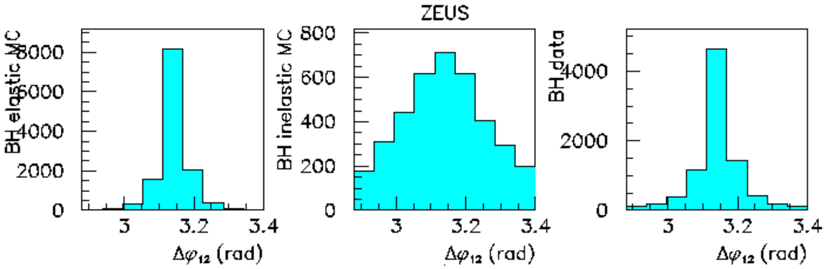
Elastic BH ratio

BH el. = 79.2 ± 8.0 % (2006/07)

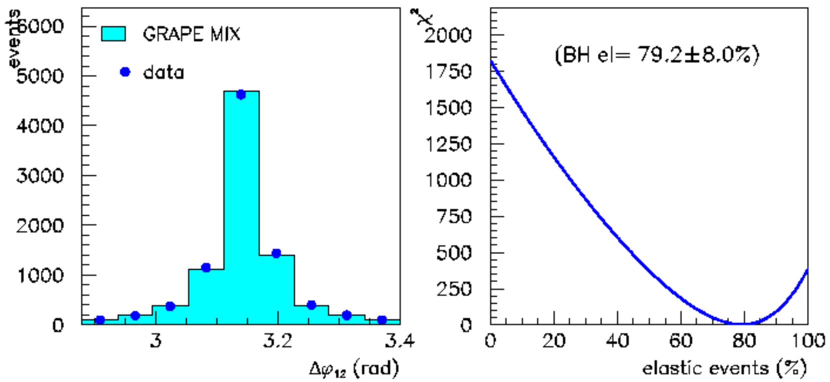
BH el. = 80.5 ± 8.1 % (2004/05)

BH el. = 84.0 ± 8.0 % (HERA I pub.)

BH contribution



MC BH elastic. MC BH inel. BH data



T
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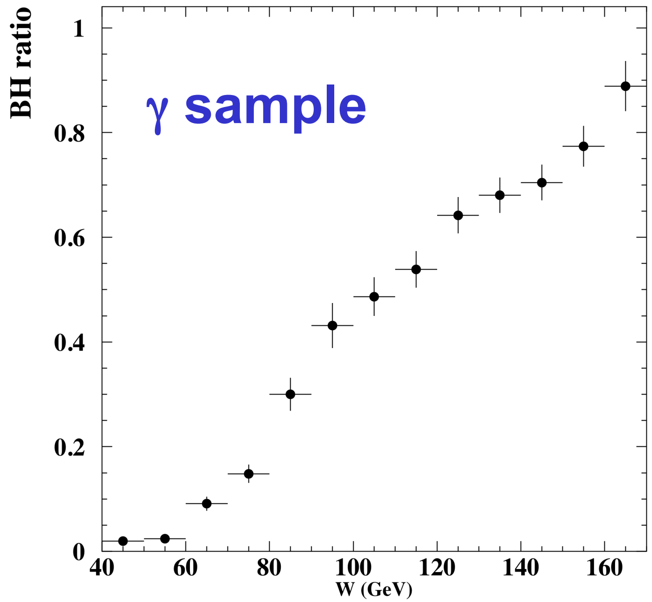
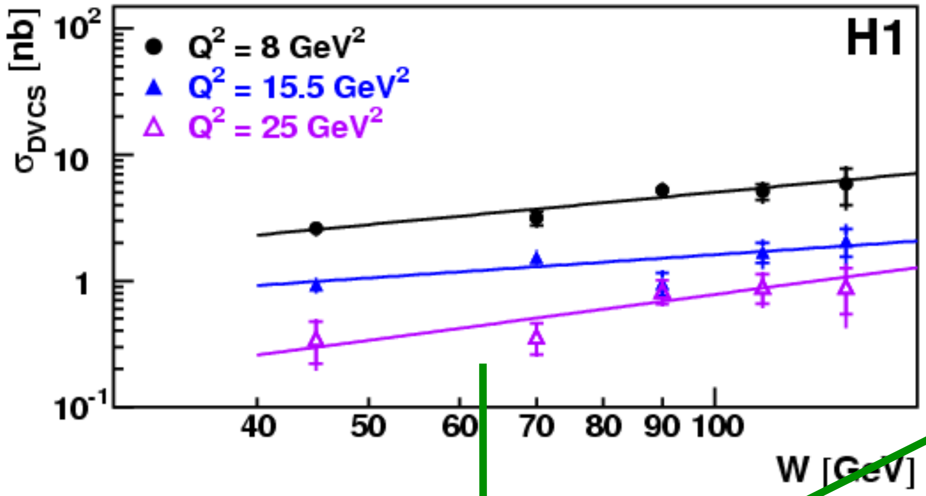
and

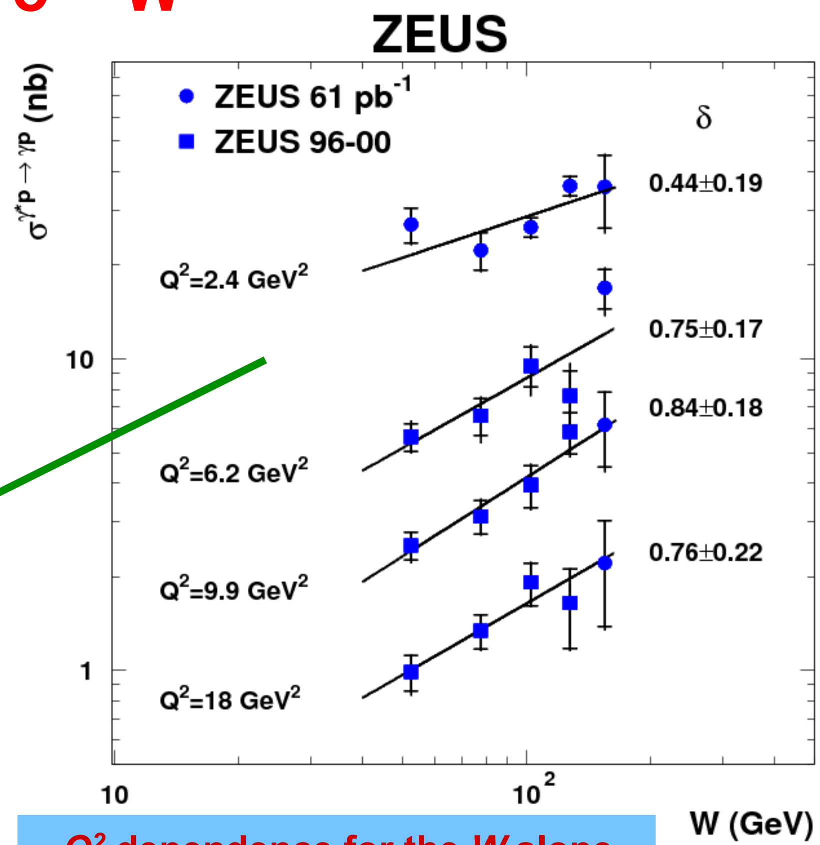
Fraction of BH in the γ sample bin by bin vs W

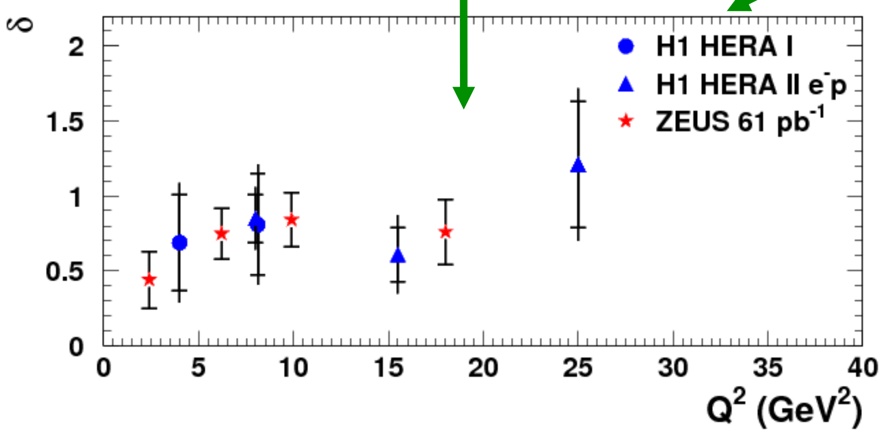


DVCS: *W*-dependence

Fit: $\sigma \sim W^{\delta}$







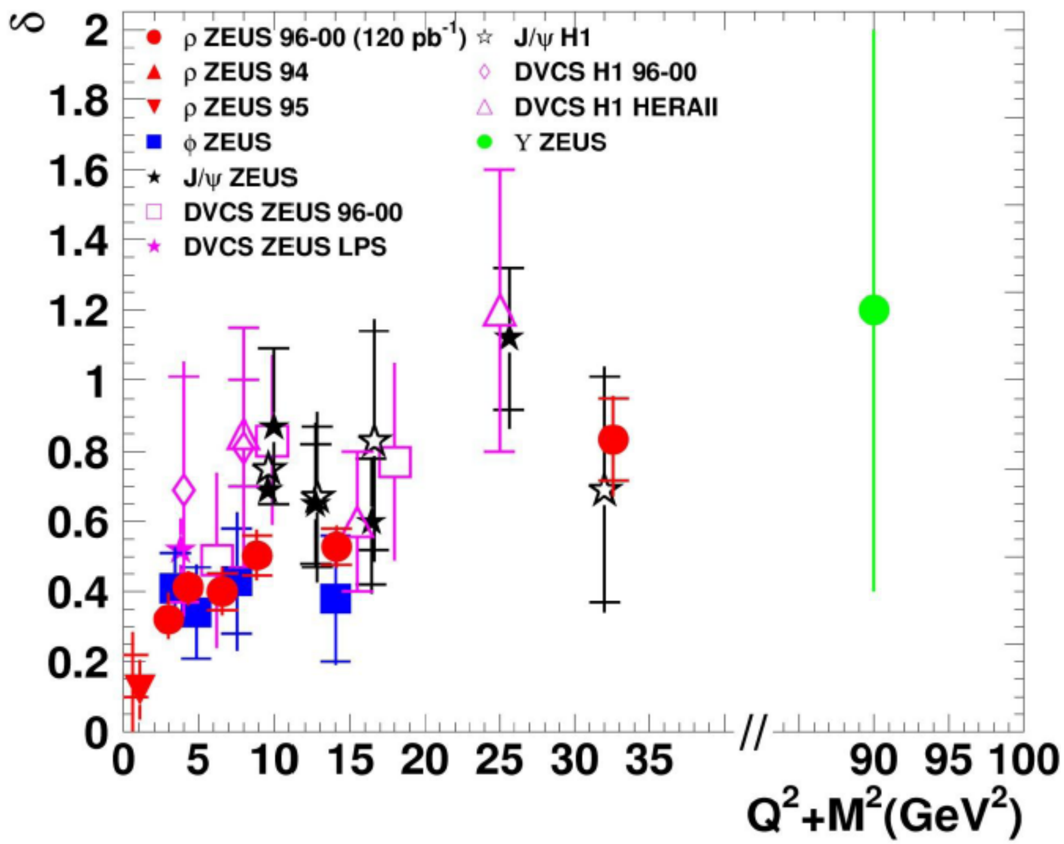
Q^2 dependence for the *W* slope not clear within the uncertainties!

ZEUS: JHEP05(2009)108
H1: Phys.Lett.B659:796-806,2008

W-dependence: summary

Summary of the W-dependence for all VMs + DVCS measured at HERA

W-slope is $(Q^2 + M_V^2)$ scale dependent

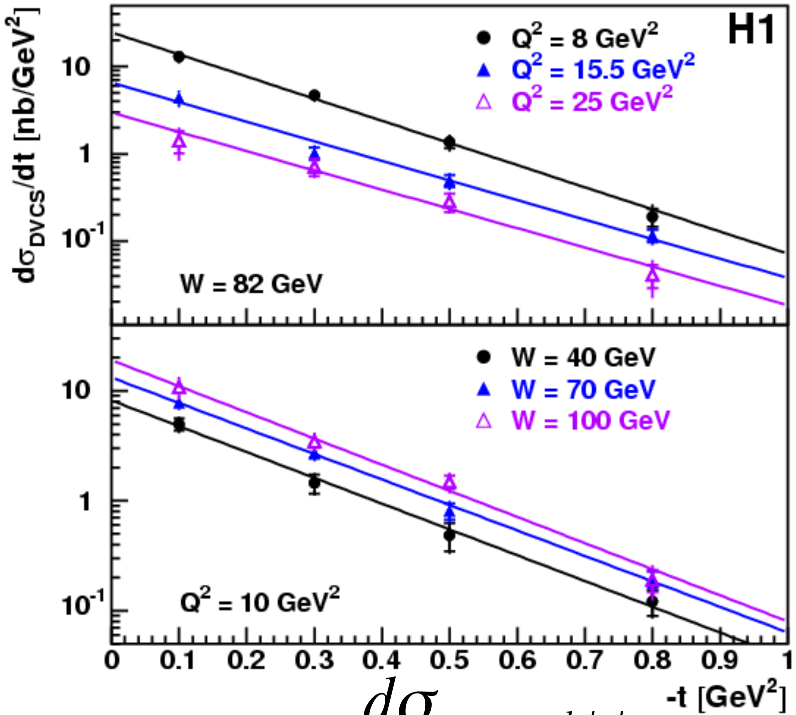


Fit: $\sigma \sim W^{\delta}$

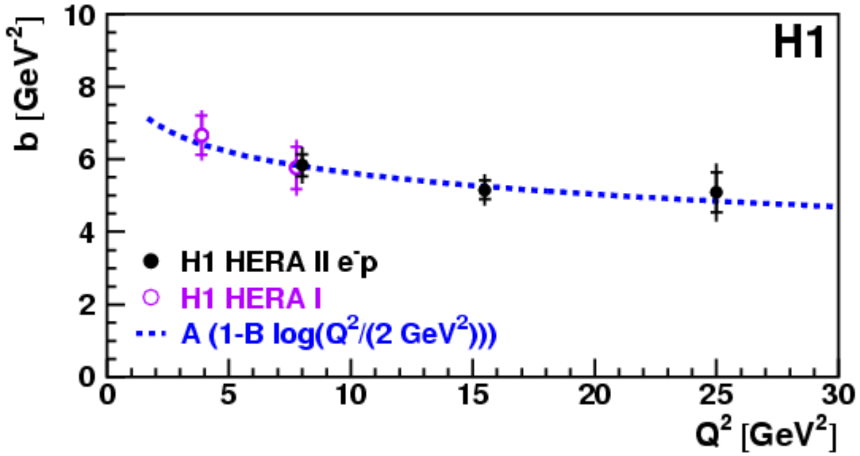
t dependence

The measured indirectly:

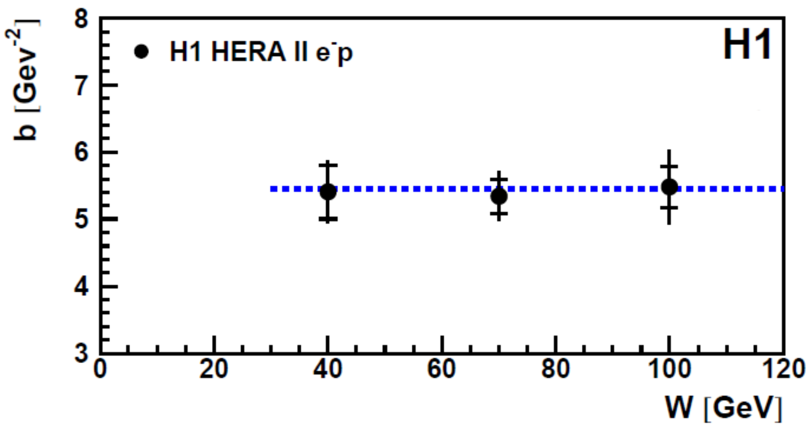
$$t \sim \left(P_{T\gamma}^2 + P_{T_e}^2\right)^2$$



$$Fit: \quad \frac{d\sigma}{dt} \propto e^{-b|t|}$$



b* decreases with increasing *Q^2

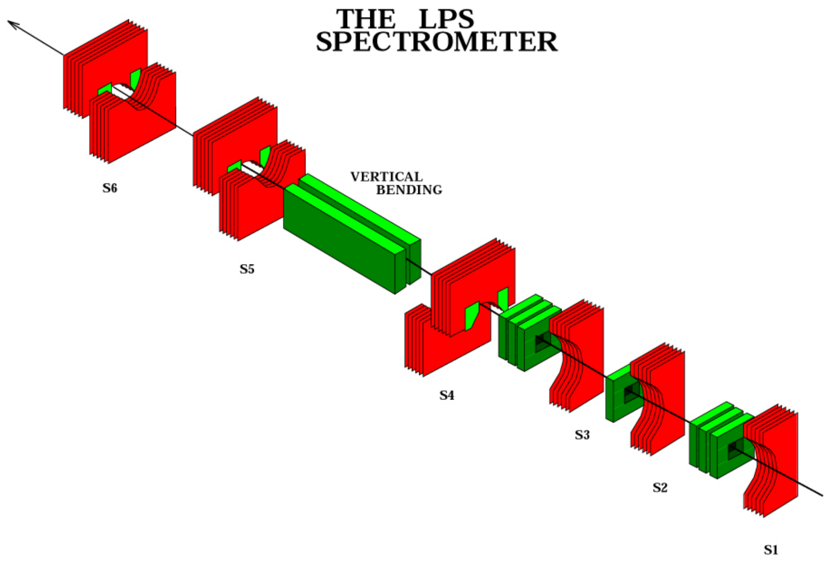


No evidence for *W* dependence of *b*

LPS selection criteria

- 3 < Q^2 < 100 GeV^2
- 40 < W < 170 GeV
- ZEUS selection cuts

L = 27.77 pb^{-1}



LPS selection Cuts:

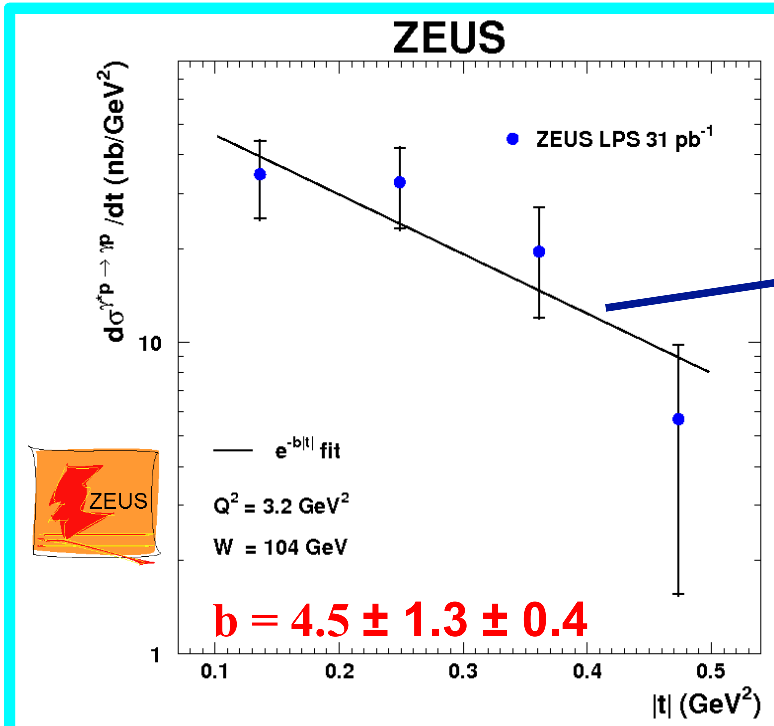
- 2000 data only
- 0.96 < x_L < 1.04
- 0.08 < |t| < 0.53 GeV^2
- LPS track position cut
- E+pz +1840·x_L<1865 GeV
- docap > 0.04 cm

$$t = -\frac{p_t^2}{x_L} = \frac{\sqrt{p_x^2 + p_y^2}}{x_L}, \quad x_L = \frac{p'}{p}$$

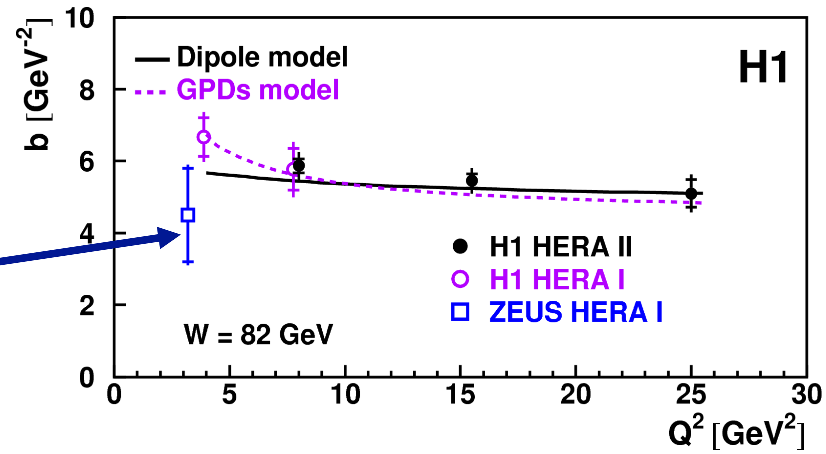
No p dissociation background → Clean measurement

Low detector acceptance → **low statistics**

t dependence



$d\sigma$/dt measured for the first time by a direct measurement of the outgoing proton 4-momentum using the LPS spectrometer



The ZEUS result is in agreement with H1

…nevertheless it seems to suggest a lower trend!

VM: *t* dependence

Same slope for all VM vs (Q^2 + M^2)

Size of the gluons:

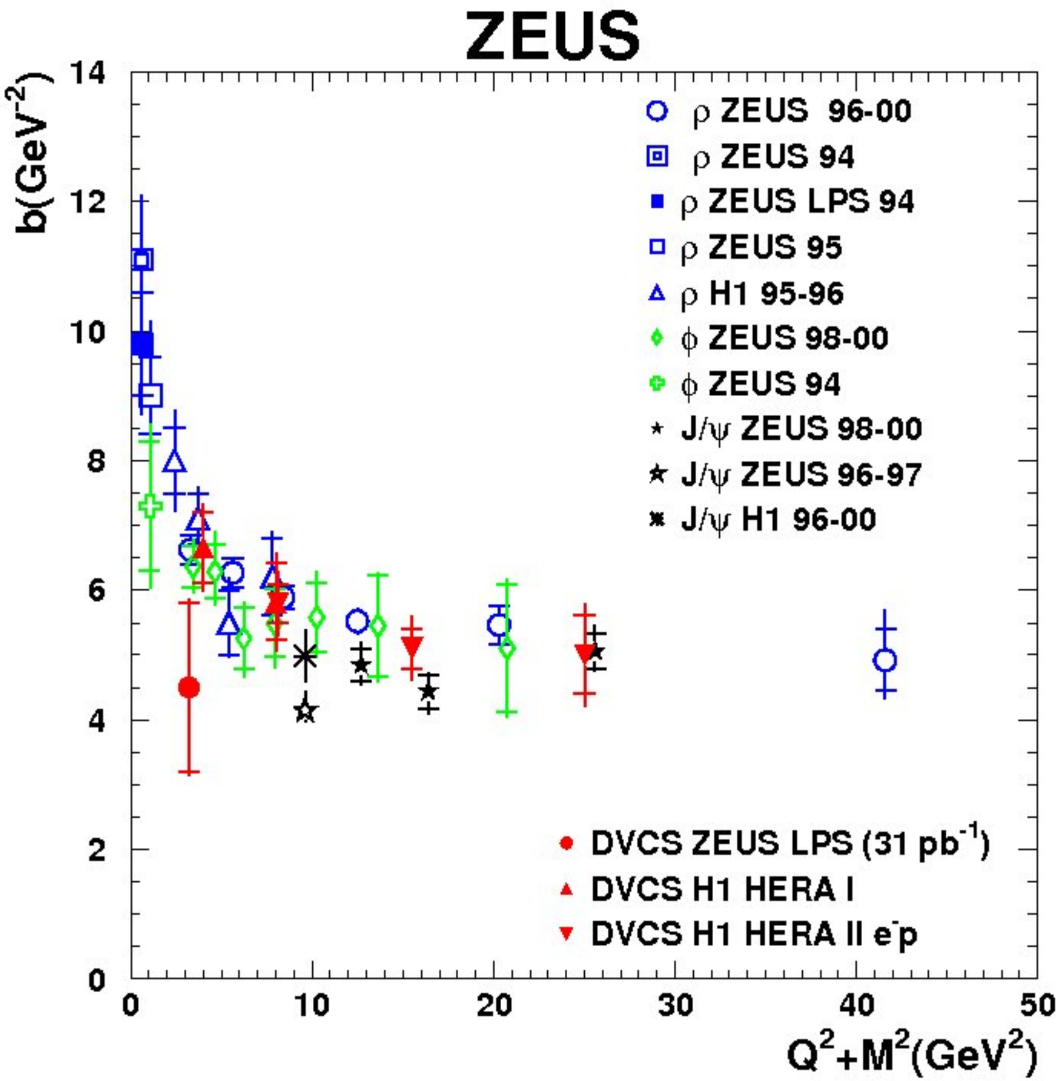
$$\langle r^2 \rangle = 2 \cdot b \cdot (\hbar c)^2$$

$$r_{glue} = 0.56 \text{ fm}$$

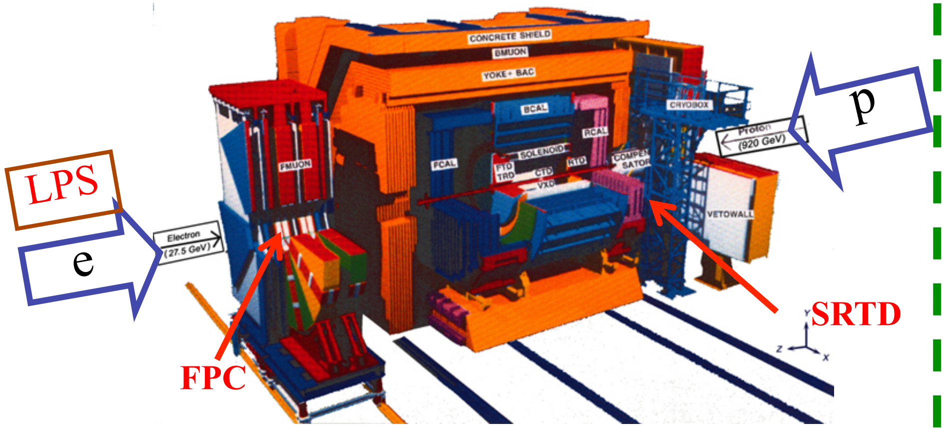
Proton radius:

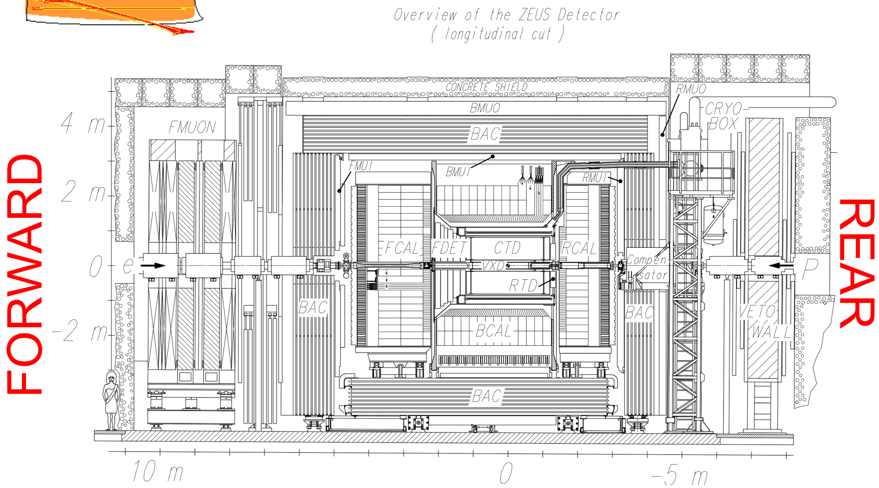
$$r_{proton} = 0.8 \text{ fm}$$

Gluons confinement area is smaller than proton



from ZEUS to new detector @ EIC



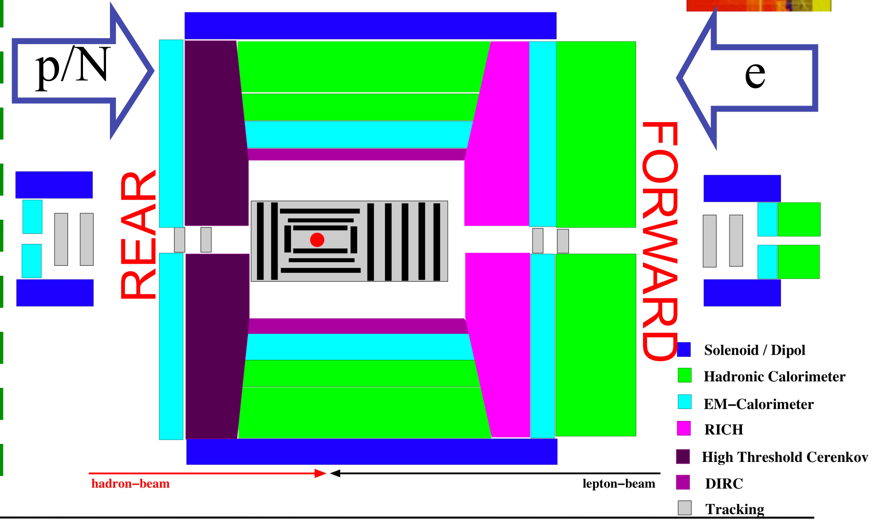


Similarities:

- Hermetic
- Asymmetric

Important (possible) improvements:

- Central Tracking Detector
- better em calorimeter resolution
- Very forward calorimetry
- Rear Trackers!
- **Roman pots (crucial!)**



And at EIC…?

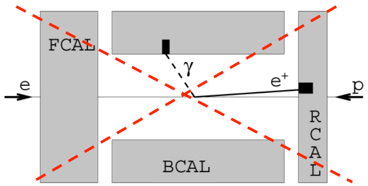
To successfully measure t indirectly from the electron and photon candidates

$$t \sim \left(P_{T_\gamma}^2 + P_{T_e}^2\right)^2 =$$

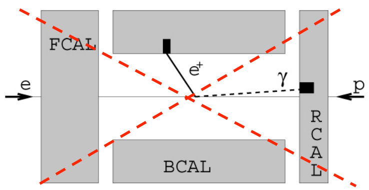
it is important:

❖Tracker coverage (tracker has higher momentum resolution than Cal!)

Reso of the CTD @ ZEUS: σ(pT)/pT =0.0058pT⊕0.0065⊕ 0.0014/pT



DVCS/BH



BH

Red dashed line shows the CTD acceptance at ZEUS

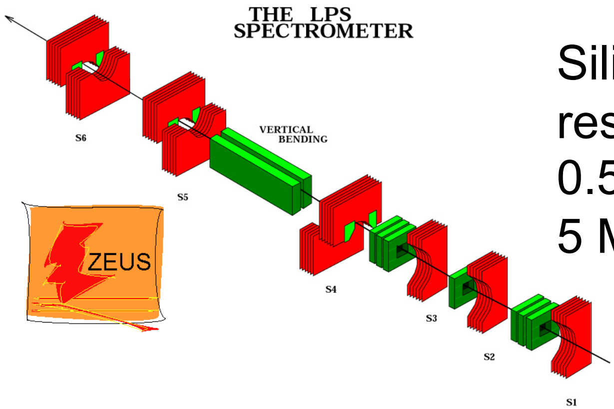
Always measure a track when we can -> better momentum resolution but not only… More acceptance for DVCS!! See the cut on $\theta_\gamma > 2.8$ rad

❖High resolution em calorimetry (crucial! Remember that one particle is a photon!)

For ZEUS it was *σ(E)/E=0.18/√E* and was too week for good t resolution

And at EIC…?

But… is an indirect measurement of t really an issue for EIC?
We'll get roman pots in the forward region at EIC!



Silicon micro-strips resolution:
0.5% for P_L
5 MeV for P_T

$L = 27.77\ pb^{-1}$

55 events (DVCS + BH)

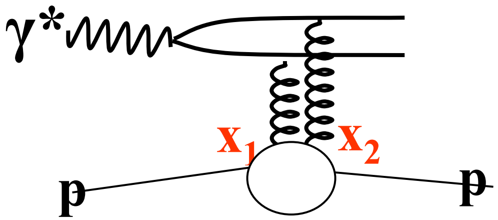
for eRHIC: $1.4\ 10^{34} * E_p/325\ cm^{-2}s^{-1}$
assuming 50% operations efficiency one week corresponds to:
$L(1\ w) = 0.5 * 604800(s\ in\ a\ week) * (1.4x10^{34}\ cm^{-2}s^{-1}) = 4*10^{39}\ cm^{-2} = 4000pb^{-1}$

+ Roman Pots → ~ 7900 events/week !!

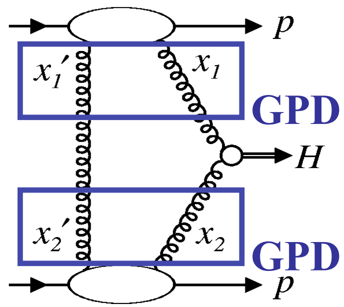
assuming the same acceptance ad LPS (~2%)

Calculations are absolutely not rigorous! But give an idea…

The DVCS and GPDs



x1 ≠ x2 → **Generalized Parton Distributions: sensitive to the correlations in the proton**



GPDs are important also for the diffractive Higgs production at the future LHC experiments at CERN in Geneva

$$|A|^2 = |A_{DVCS}|^2 + |A_{BH}|^2 + |A_I|^2$$

DVCS and BH: identical final state → they Interfere

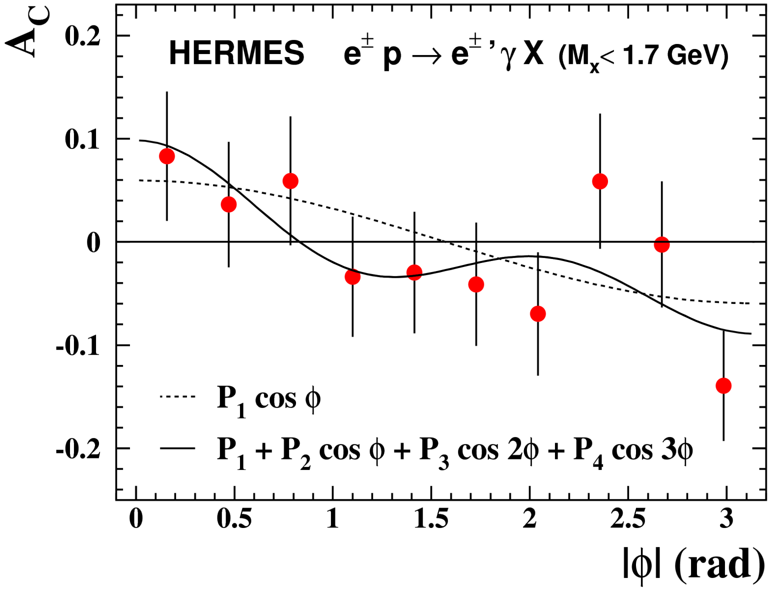
Interference term: $A_I \propto Re(A_{DVCS}) + Im(A_{DVCS})$

Beam charge asymmetry: $A_C = \dfrac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto Re(A_{DVCS})$

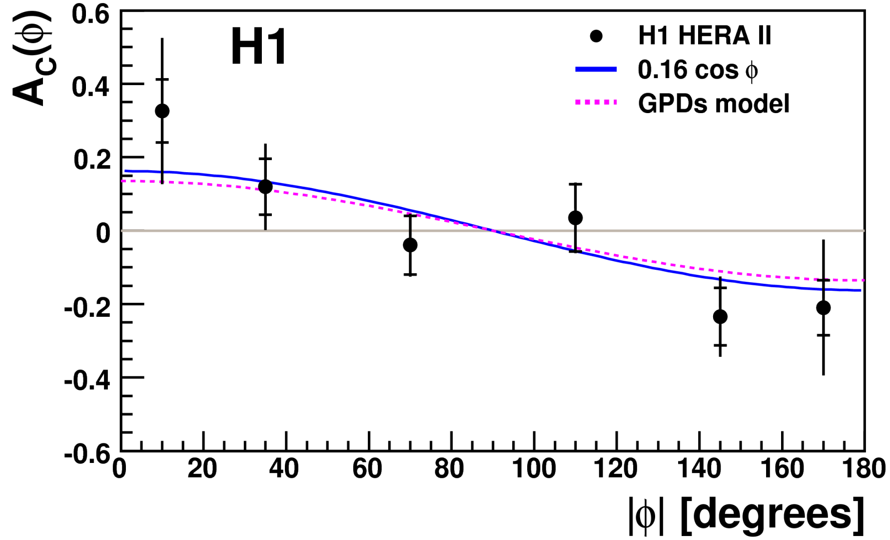
DVCS: the beam-charge asymmetry

The beam charge asymmetry as a function of phi

HERMES

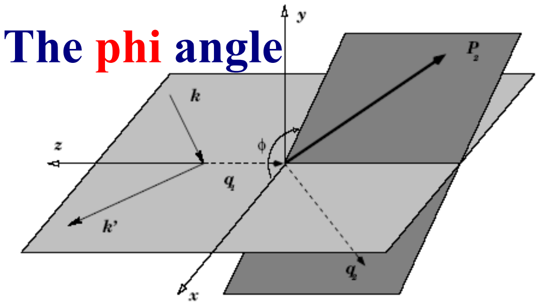


H1



$$A_C = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-}$$

The phi angle



At ZEUS:

At EIC:

We need positrons!!

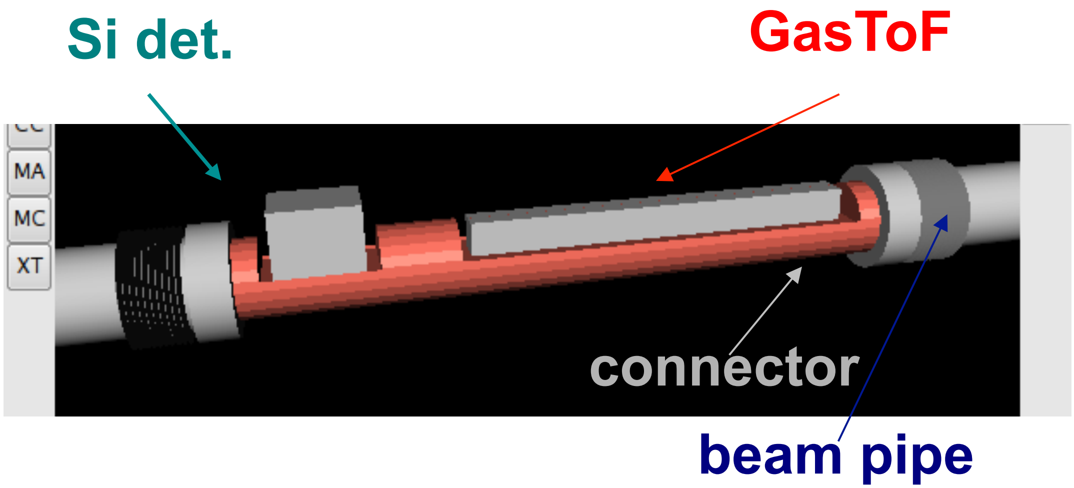
And again… a good tracker coverage

Summary

- **A lot of experience carried over from HERA**
- **DVCS is the best tool for GPDs investigation**
- **EIC forward program can sensibly improve HERA**

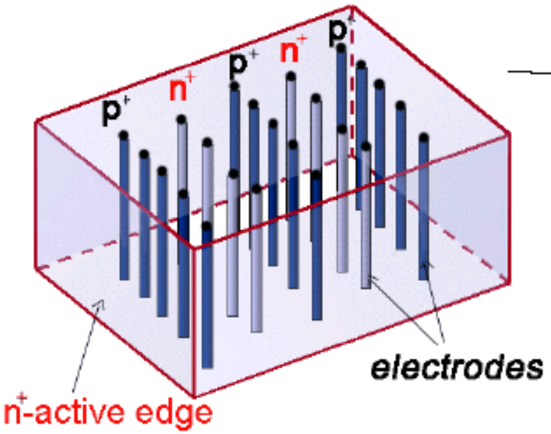
Back up

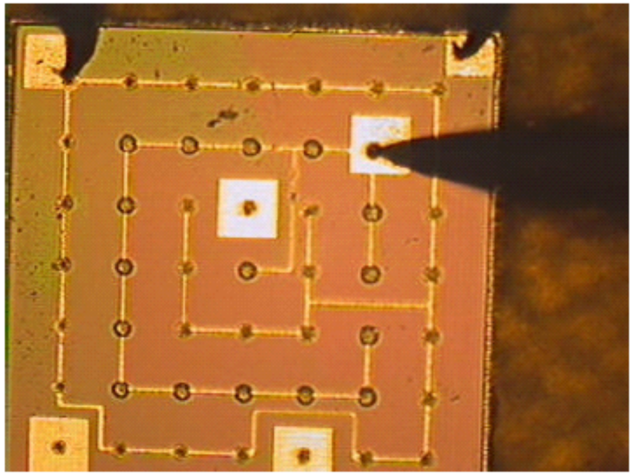
The movable beam pipe concept



3D DETECTORS AND ACTIVE EDGES

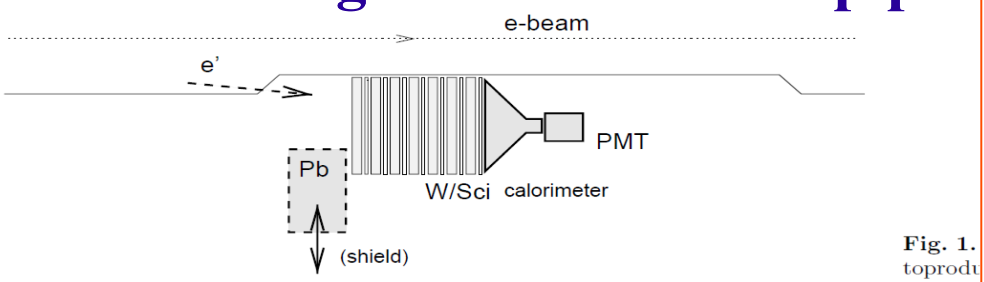
Brunel, Hawaii, Stanford



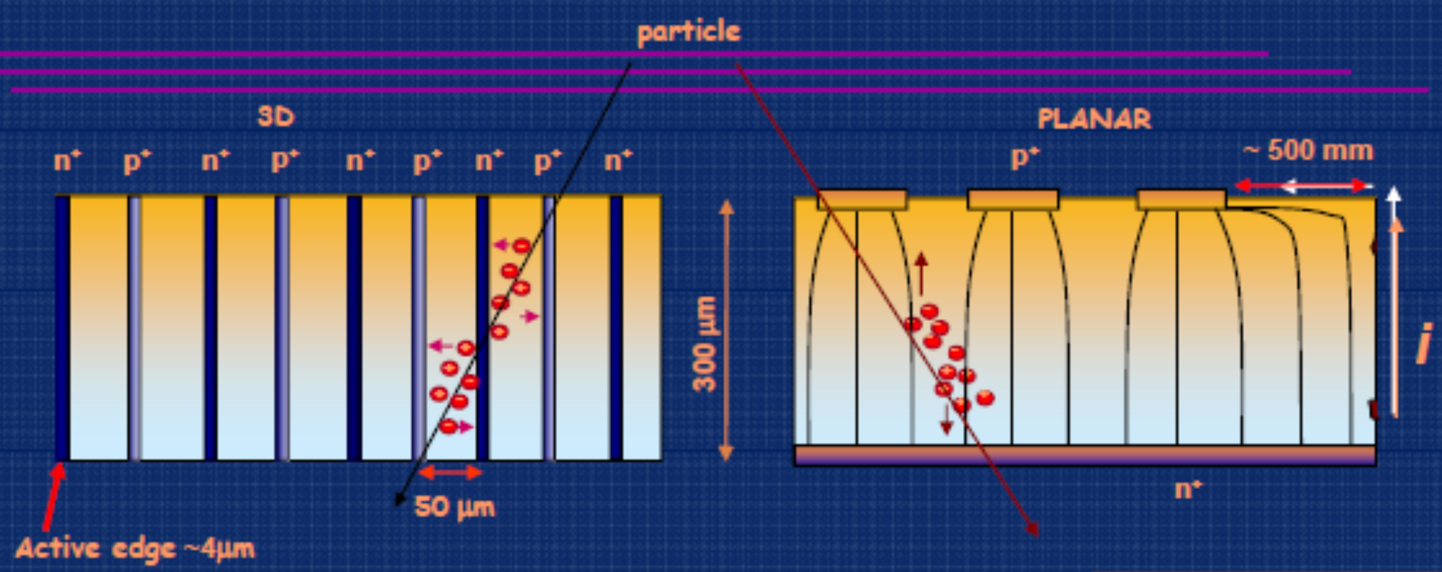


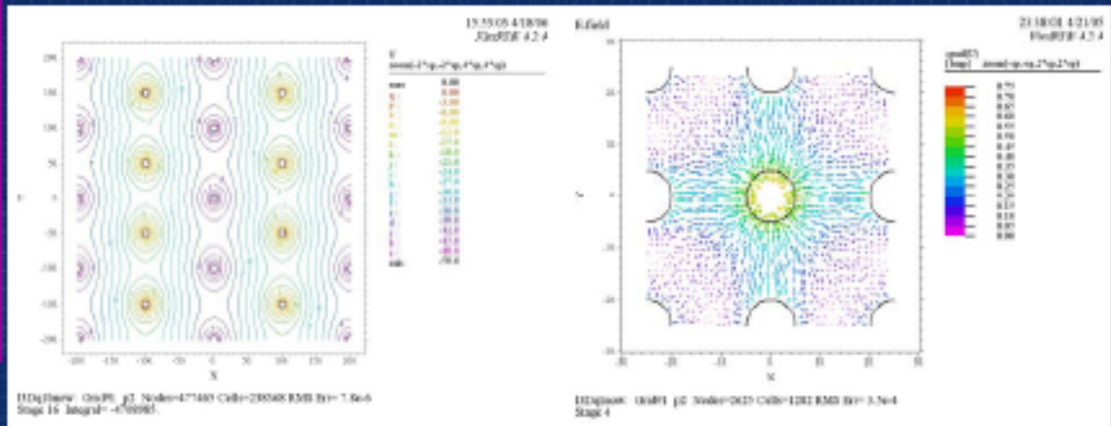
Need to approach beam to mm level

"Hamburg" movable beam-pipe



What's different→3D versus planar



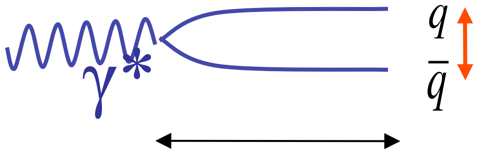


	3D	planar
V_{dep}	< 5-10 V	50-70 V
Q_{1mip}	24000e-	24000e-
C	40-80fF	50-200fF
Lorentz angle	no	yes

Simulations using FlexPDE by S. Watts (Manchester)

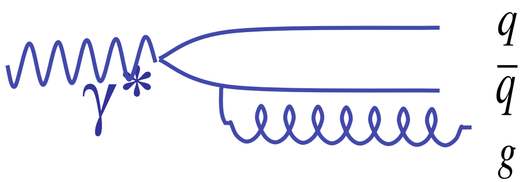
The colour dipole picture

Virtual photon fluctuates to $q\bar{q}$, $q\bar{q}g$ states (colour dipoles)



$$\frac{1}{\sqrt{Q^2 + M^2_{q\bar{q}}}}$$

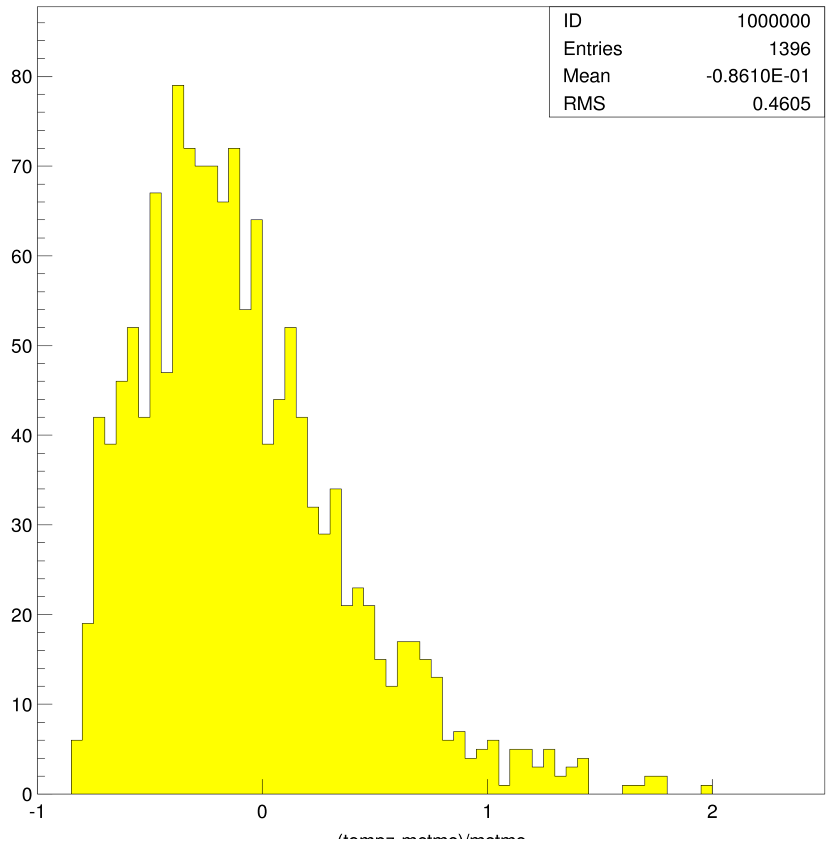
$$E_\gamma \sim W^2 \sim 1/x$$



- Lifetime of dipoles very long → it is the dipole that interacts with the proton This is why can do diffraction in ep collisions!
- Transverse size $1/\sqrt{(Q^2 + M_{q\bar{q}}^2)}$

Transverse size of incoming hadron beam can be reduced at will. Can be so small that strong interaction with proton becomes perturbative!

Poor resolution at ZEUS



(t_ric – t_gen) / t_gen